EFFECT OF MISSING 30KV NEUTRAL WIRE ON NETWORK BEHAVIOR

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ABSTRACT

Authors aim to present through this paper the behaviour of 30kV overhead network divested of its neutral conductor. Work is based on simulation, network testing and pilot site experimentation feed back.

As pertinent result, it was found that distributed multi grounded neutral conductor is but an expensive way for helping only to take down power frequency earthing resistance; however its expense is not worth function.

INTRODUCTION

Tunisian distribution system is made of 10, 15 and 30 kV grids. 10 and 15 kV networks are erected according European standard based on high impedance neutral earthing. As for 30 kV network, it's designed conformable to north American standard well known as effectively earthed neutral system as its temporary overvoltage should not exceed 80% phase to phase voltage [1].

For around two decades, most of our overhead 30 kV network are satisfactory exploited despite they are divested of MV neutral conductor. All concerned feeders are operated without any perceptible effect either on system protection or safety.

This paper presents study led by Tunisian electric utilities in trial to detect eventual effect of missing MV neutral conductor on network behaviour; however following topics have been developed : Temporary overvoltage and network protection and security.

It was turned out that temporary overvoltage does not exceed the permissible limits despite of missing whole neutral conductor, also no negative issue on network safety or protection was identified. These outcomes are predictable as feeders are already being used while satisfying for a long-time without any hazards linked to neutral wire missing.

EFFECT ON TEMPORARY OVERVOLTAGE

Three wire overhead line earth return modeling

In case of missing neutral conductor, complex depth method will be the appropriate one for modeling overhead 30 kV feeder (Fig.1) as return current will be flowing through the ground [2]; However proper and mutual inductance denoted L_{ii} and M_{ij}, will be computed according this method respectively by mathematical statement (1) and (2) :

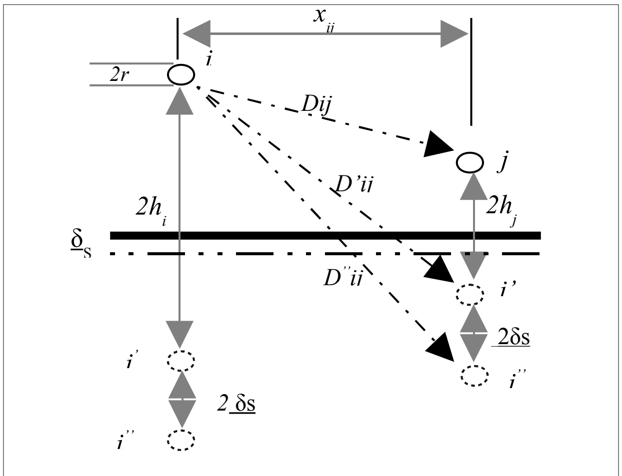

Fig.1: *Overhead line with earth return model*

$$L_{ii} = \frac{\mu_0}{2\pi}.Ln\left(\frac{2(h_i+\delta_s)}{R_{MGi}}\right) + \mu_0/8\pi \quad (1)$$

$$M_{ij} = \frac{\mu_0}{2\pi}.Ln\left(\frac{(h_i+h_j+2\delta_s)}{D_{ij}}\right) \quad (2)$$

$$\delta_s = \sqrt{\frac{\rho_s}{\mu_r.\mu_0.p}} \quad (3)$$

Where:

D_{ij} : designates distance between conductors 'i,j' (m). h_i is average height of conductor 'i' above ground (m). $\mu_0=4\pi 10^{-7}$(H/m). $h_i = h_{ip}-2F_i/3$ (m). h_{ip} : is conductor 'i' height measured at pole (m). F_i is conductor 'i' mid span sag (m). δ_s : is the complex depth, p= jω, ω is the grid pulsation (rd/s). ρ_s : is soil electric resistivity (Ωm).

R_{GMi} : Mean Geometric Radius of conductors "i"; it depends on its strands number and cross section "s", as shown in (Tab.1).

30kV feeder typical geometry (Tab.2) will be considered

Tab.1: *Conductor Mean Geometric Radius*

Strands number	7	19	37
R_{MG}	$0,4642\sqrt{s}$	$0,4902\sqrt{s}$	$0,4982\sqrt{s}$

***Tab.2:** Conductors spacing and height to ground surface*

	Phase 1	Phase 2	Phase 3	Ground
Phase 1	-------------	1,95m	3,02m	10,15m
Phase 2	-------------	-------------	1,95m	10,65m
Phase 3	-------------	-------------	-------------	10,15m

Temporary overvoltage simulation

Temporary over-voltage [3] coefficient “K_u” is computed according (4) :

$$K_u = \max[\text{module}(K_{u1},K_{u2})/\sqrt{3}] \tag{4}$$

Where :

$$K_{u1} = \frac{a-1}{Z_d+Z_i+Z_0}(aZ_i - a^2 Z_0) \tag{5}$$

$$K_{u2} = \frac{a-1}{Z_d+Z_i+Z_0}(aZ_i + Z_0) \tag{6}$$

Z_d, Z_i and Z_0 : Designate respectively positive, negative and zero sequence impedance. $a=e^{j2\pi/3}$: is the complex operator

Simulations of 'K_u' was conducted with following data
- Phase conductor cross section : s=148,1mm² Aluminium alloy, 19 strands.
- The Fault resistance is null; corresponding to most constraint case where overvoltage reaches highest value
- Earthing transformer zero impedance : Z_{0TPN} = 9 Ω/phase
- Power transformer internal Impedance and rating power S_n = 40MVA, U_{cc} = 12% .

Overvoltage simulation (Fig.2) assumes full single phase earth fault and soil resistivity varying in the range up to 10^4Ωm.

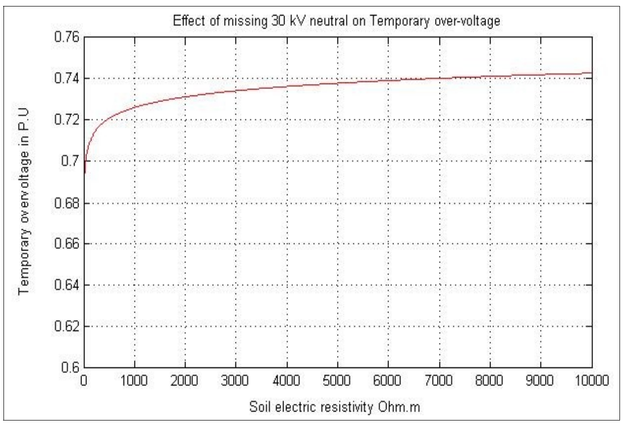

***Fig.2:** Overvoltage simulation*

Simulation results show that temporary overvoltage coefficient does not exceed 0,8; therefore 30 kV network remains considered as an effectively neutral earthed system what ever MV neutral is distributed or not.

Experimental validation

Site measurements have been conducted on 30kV feeder arising from 'SIDI BOUZID' 150/30 kV substation. It's a question of identifying experimentally feeder impedance matrix then deducing temporary overvoltage. Following results have been obtained :

First case : Feeder equipped with distributed and multi-grounded neutral conductor; matrix determined on site is:

$$[Z]=\begin{bmatrix} 2{,}88+j3{,}66 & 1{,}47+j1{,}37 & 1{,}47+j1{,}15 \\ 1{,}47+j1{,}37 & 2{,}89+j3{,}65 & 1{,}47+j1{,}41 \\ 1{,}47+j1{,}15 & 1{,}47+j1{,}40 & 2{,}89+j3{,}74 \end{bmatrix}\Omega$$

Corresponding cyclic impedance Matrix is :

$$[Z_s]=\begin{bmatrix} 1{,}42+j2{,}38 & -0{,}16+j0{,}08 & -0{,}04-j0{,}06 \\ 0{,}15+j0{,}08 & 1{,}42+j2{,}37 & 0{,}04-j0{,}06 \\ 0{,}03-j0{,}06 & -0{,}04-j0{,}06 & 5{,}82+j6{,}30 \end{bmatrix}\Omega$$

Deducted temporary overvoltage coefficient is : K_u = 0,76

Second case : Overhead line was divested of its neutral conductor; matrix determined on site becomes :

$$[Z]=\begin{bmatrix} 1{,}51+j4{,}56 & 0{,}12+j2{,}27 & 0{,}13+j2{,}00 \\ 0{,}12+j2{,}26 & 1{,}54+j4{,}52 & 0{,}12+j2{,}27 \\ 0{,}13+j2{,}00 & 0{,}13+j2{,}25 & 1{,}51+j4{,}53 \end{bmatrix}\Omega$$

Corresponding cyclic impedance Matrix is :

$$[Z_s]=\begin{bmatrix} 1{,}41+j2{,}36 & -0{,}16+j0{,}09 & -0{,}09-j0{,}03 \\ 0{,}15+j0{,}11 & 1{,}39+j2{,}36 & 0{,}08-j0{,}03 \\ 0{,}07-j0{,}04 & -0{,}08-j0{,}04 & 1{,}77+j8{,}88 \end{bmatrix}\Omega$$

Deducted temporary overvoltage coefficient is : K_u = 0,79

Theoretical as well as practical results show that 30kV network is an effectively earthed neutral system type regardless distribution of MV neutral conductor which accordingly helps only to take down overall earthing resistance by interconnecting earthing rods scattered on the network. Effect on protection and security has to be checked as both of single phase short circuit level and voltage contact depend on steel pole earthing resistance.

EFFECT ON PROTECTION AND SECURITY

Following topic will be dedicated to study the effect of missing MV neutral conductor on security and protection system efficiency.

Effect on contact voltage

Voltage contact is but the voltage drop generated by unbalance current through transformer MV neutral earthing resistance “R_n”. It concerns pole mounted three phase distribution transformer. According to Tunisian standard [4], contact voltage should not exceed 25 Volts. Consequently for fully loaded transformer those residual current around 30% of its rating one; contact voltage will be kept within safety limits if following condition (7) is filled :

$$R_n < 25/(0{,}3*I_n) \quad (7)$$

Earthing resistance satisfying security from voltage contact point of view depends on transformer size (Tab.3) :

Tab.3: *Safety earthing resistance 'R_n'*

Transformer size in kVA	3X25	3X50	3X150
R_n in Ω, satisfying security	52,0	26,0	8,7

STEG distribution guide [5] postulates that transformer individual earthing resistance must not exceed 3Ω ; this requirement by itself satisfies amply security condition and exempts our utilities of distributing MV neutral conductor along 30kV network.

Effect on system Protection efficiency

In case of missing neutral conductor, earth fault current will be moderated by pole earthing resistance “R_s”. Over-current relay set to 60 A, will clear any fault occurring within a perimeter 'd' determined by (8) as function of line profile (Tab.4).

$$\text{module}[3*V/(d*(z_d+z_i+z_o)+5Z_T+3R_S]>60 \quad (8)$$

Tab.4: *Relay monitoring area perimeter*

	Protected area perimeter (km)				
S = 54,6mm²	214	203	192	158	98
S = 148,1mm²	359	347	335	292	201
R_s in Ω	0	10	20	50	100

Where :

z_d, z_i and z_o: Designate respectively feeder positive, negative and zero sequence linear impedance (Ω/km).

S : is the phase conductor cross section

d : Designate fault location (km).

Z_T : Power transformer impedance (Ω)

Above table (Tab.5) show that protection monitoring perimeter covers whole faults occurring at 200 or 100km from HV substation respectively for phase conductor cross section 148,1 or 54,6mm², even for high steel pole earthing resistance. Tests have been performed on 30kV feeder unequipped with MV neutral conductor, by shorting one phase conductor to steel pole whose earthing resistance is “Rs=52Ω”. Fault was initiated at the end of main branch and it was correctly cleared.
Practical test proves once more that missing neutral conductor does not impede system protection efficiency as main branch does never exceed 100km.

EFFECT ON LIGHTNING PROTECTION

Surge arrestor and transformer MV neutral are commonly grounded through earthing rods witch is systematically connected to MV neutral because it was thought that the latter discharges almost all residual current as it's multi-grounded; based on this belief no following up is foreseen for earthing system. That's why we will assess MV neutral conductor performance at higher frequency!

MV neutral conductor modeling

MV neutral could be modeled by cells cascade [6], each cell is made of longitudinal and transversal impedance corresponding respectively to neutral span impedance “Z=R+jX ” and pole earthing resistance “Rs” (Fig.3).

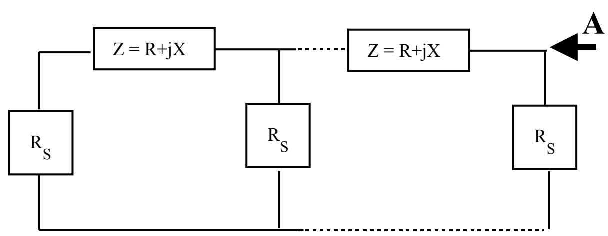

Fig.3: *MV neutral conductor model*

Simulation of MV neutral impedance

Simulation reveals that MV neutral impedance increases indefinitely with frequency (Fig.4), thereby preventing flowing of lightning current witch will be accordingly diverted to transformer earthing rods. Simulation was run for following site conditions: Z=(0,0624+j0,0381) Ω at 50Hz, 11Ω<Rs<23Ω, span length = 100m.

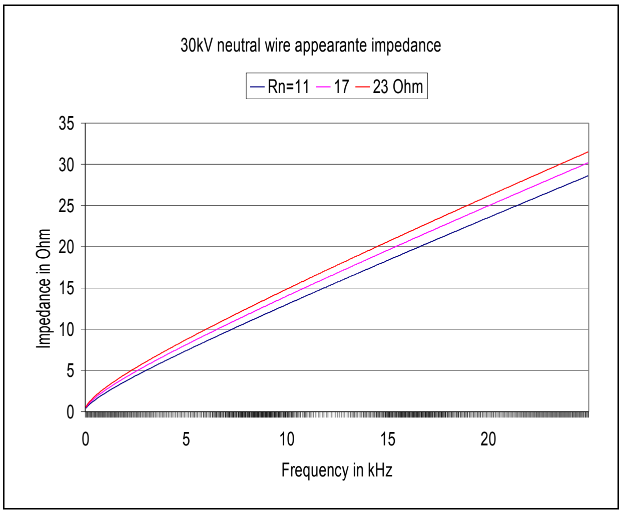

Fig.4: *MV neutral simulated impedance versus frequency*

Experimental validation

Measurements of MV neutral, earthing rod and their equivalent impedance were performed on above mentioned site. Recorded measures (Fig.5) are found coherent with simulation results validating hence the model.

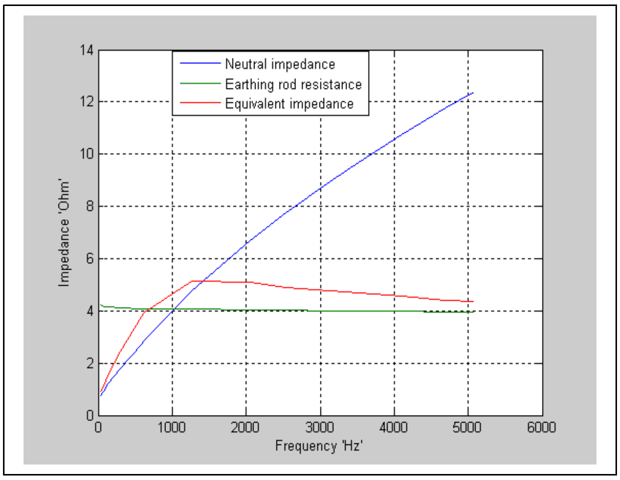

Fig.5: *Measured impedances versus frequency*

Experimental results also show that smooth functioning of lightning arrestor will be impeded as the equivalent impedance at higher frequency is greater than earthing rod resistance itself; instead of mitigating it!.

However we had rather to disconnect all earthing rods from MV neutral conductor; so what's then its duty?

PILOT SITE FEEDBACK

Aware that these results won't be easily assimilated and in trial to be more convincing, a pilot site was selected and following feed back experience was recorded:

- 442km three phase 30kV network unequipped with MV neutral are being successfully used for more than one decade.
- Measurements reveal none contact voltage out of safety range and no damage neither complains related to missing MV neutral are recorded
- No protection disabling, security trouble or dysfunction are detected neither does take place at overall districts.

CONCLUSION

Following pertinent results have to be highlighted :

- Multi-grounded MV neutral is but a way to minify overall earthing resistance at power frequency and amplify it during lightning discharge impeding then surge arrestor smoothing operation.
- In goal to provide lightning protection margin to transformer, special care is mandatory to each earthing rod what ever MV neutral is distributed or not as surge arrestors are generalised in our 30kV network.
- Apart from daily routine, distribution of neutral conductor seems unnecessary and its 3000USA Dollars per km expense does not match its function.

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